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Passive Athermal-Packaged Tunable Fiber Bragg Grating for OADM's

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Abstract: Wavelength selectivity and temperature insensitivity of fiber Bragg gratings are simultaneously achieved by using a bending bimetal structure with a spring. The Bragg wavelength shift is less than 0.1nm from −20°C to 80°C and the switching wavelength range can be 0.8nm with the switching time less than 8ms.

Introduction

Recently tunable fiber Bragg gratings (TFBGs) have been extensively studied for their potential applications in re-configurable optical add/drop multiplexers for dynamic network management. [1-3] However, the temperature sensitivity of TFBGs is a major factor limiting their practical applications. For commercial telecommunication systems, it is essential to ensure that the Bragg wavelength of TFBGs has a temperature sensitivity less than 0.01nm/°C within the whole operative spectral regime. Movere, passive temperature compensated method [1] is usually preferred because it does not need additional power for thermal stability. In this letter, we propose and demonstrate a simple yet novel method that can simultaneously achieve wavelength switch and excellent temperature insensitivity of FBGs. The module does not require continuous power to maintain the wavelength shift and the switching time is less than 8 ms. In addition, the temperature dependence of Bragg wavelength is less than 0.001nm/ °C over the working temperature range from -20 °C to 80 °C for all the operation wavelengths. Our scheme has several advantages including simple structure, high thermal stability, and high accuracy of wavelength tuning.

Principle

The Bragg wavelength λ_B of a uniform FBG is sensitive to the ambient temperature and applied external strain. Thus, the Bragg wavelength of FBG can be simply tuned by applying a suitable external strain. However, in order to achieve simultaneously wavelength tunability and temperature insensitivity, the applied strain needs to be suitably varied when the temperature is changed.

Fig.1 illustrates the schematic structure of our temperature compensated TFBG package. The FBG is mounted under tension on one side of the bimetal strip with a lower thermal expansion coefficient. The middle of the bimetal strip is connected to a linear spring by thermal epoxy, while the other end of the linear spring is bonded to a movable block. After some derivation, we find that the bending strain ε of the bimetal strip loaded with a spring force under temperature changes can be estimated by

$$\varepsilon \approx \gamma\Delta l + \beta\Delta T \qquad (1)$$

where

$$\gamma = \frac{-8yLk}{L^3k + 4Ebt^3}, \beta = \frac{-8y\alpha Ebt^2}{L^3k + 4Ebt^3} \qquad (2)$$

y is the distance between the upper surface and the neutral surface of the bimetal strip, L is the length of the strip between bonded points, k is the stiffness of the spring, E is Young's modulus, b is the width of the bimetal strip, t is the thickness of the bimetal strip, Δl is the displacement of the movable block, and ΔT is the variation of temperature. The structure in Fig. 1 can induce strain on the fiber through temperature change of the bimetal plate or through the position adjustment of the tensile spring. After taking into account these two contributions as well as the temperature dependence of the FBG, the net Bragg wavelength change of the FBG [4] in Fig. 1 can be expressed by

$$\frac{\Delta\lambda_B}{\lambda_B} = \gamma(1-P_e)\Delta l + [\beta(1-P_e)+(\alpha+\xi)]\Delta T \qquad (3)$$

where P_e is the photoelastic constant, α is the thermal expansion coefficient of fiber, and ξ is the thermo-optic coefficient. By properly choosing the parameters of the bimetal, the spring and all the dimensional lengths, it is possible to adjust β to be equal to $-(\alpha+\xi)/(1-P_e)$. In this way, the temperature dependent term in equation (3) is made to be zero and thus the wavelength shift is independent of the temperature for different Δl values.

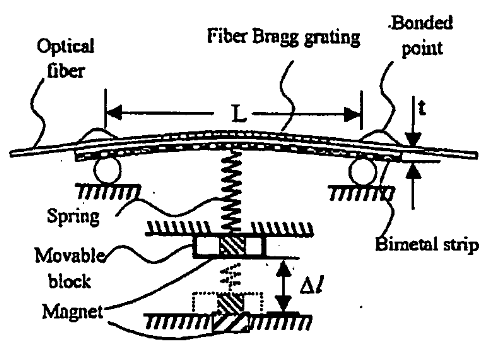

Figure 1: Schematic diagram of the tunable athermal package for fiber Bragg grating

Experiment

The FBG was fabricated in SMF-28 fiber by using a phase mask and an excimer laser. The temperature sensitivity of the bare FBG central wavelength is about 0.0116 nm/°C and the strain sensitivity is about 0.00106 nm/microstrain. Therefore, it needs an additional temperature sensitivity of approximately −10.94 microstrain/°C to compensate the temperature effect. The bimetal we use is a commercial product with a dimension of 30mm long, 2mm wide, and 0.2mm thick. The thermal deflection constant of the bimetal is

about 12×10^{-6} /°C. The stiffness of the spring could be adjusted by carefully controlling the effective ring number.

Fig. 2 shows the reflection spectrum for switching between adjecent 0.8nm channel spacing. It shows that the shape is not been changed after switching and the isolation is better than 25dB.

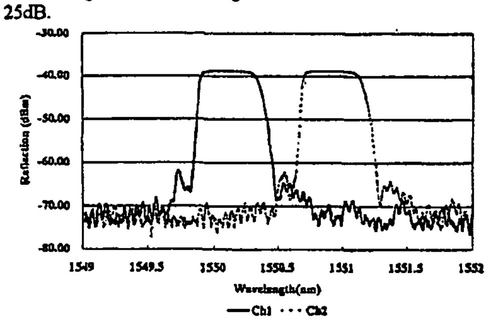

Figure 2: Reflection spectrum for switching between two adjecent channels.

Fig. 3 shows the measured wavelength shift as a function of temperature for three different positions of the tuning block. The temperature dependence of the wavelength shift is less than 0.1 nm over the range from -20°C to 80°C. These results demonstrate that our structure can indeed compensate the temperature sensitivity of the FBG regardless of the moving distance of the tunning block.

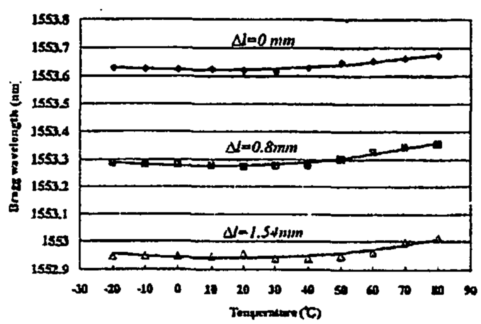

Figure 3: Wavelength shift versus the temperature for three different Δl values.

The movable block in Fig.1 is connected to an electric-magnetic device and is controlled by a computer. Fig.5 is the measurement result. The ch1 and ch2 are control signals for switching and the ch4 monitors the power of the optical signal being reflected by the TFBG. It shows that the switching time is less than 8 ms after the control signal is turn on. A magnet is used to lock the movable block (see Fig.1) and thus the device does not need electric power to sustain the wavelength shift. Fig.6 shows the wavelength repeatability of switching 1000 times between two channels. The wavelength error is smaller than 0.05nm.

Conclusion

We have proposed and demonstrated a novel athermal FBG package that can simultaneously achieve wavelength switch with excellent temperature insensitivity. The temperature

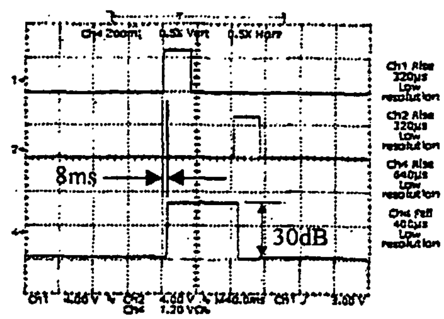

Figure 5: Experimental result for switching between 2 channels with 100 GHz channel spacing. ch1 and ch2 are the control signals and ch4 is the optical signal. The switching time is less than 8 ms.

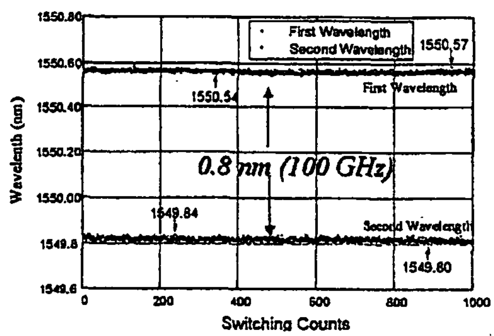

Figure 6: The Wavelength repeatability of switching 1000 times between two channels.

dependence of Bragg wavelength is less than 0.001nm/ °C from -20 °C to 80 °C and the switching time for 100 GHz channel spacing is less than 8 ms. The switching action can be controlled by computer and does not need continuous power consumption. This device linked with a pair of optical circulators can serve as a dynamic wavelength selective add/drop multiplexer [2] or a cross-connect switch with excellent temperature insensitivity.

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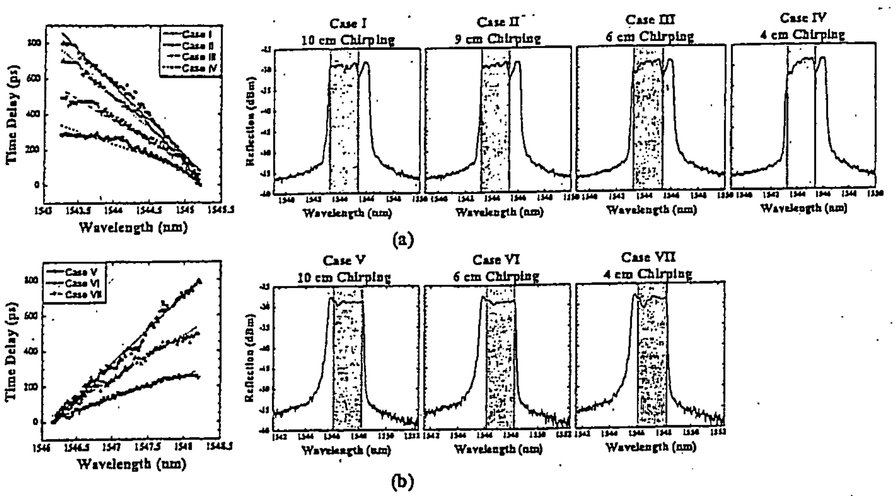
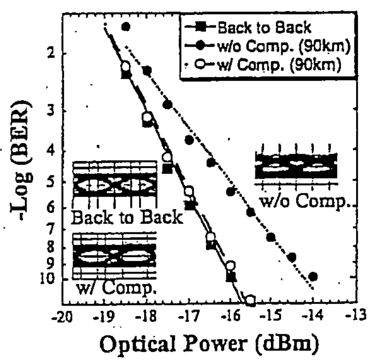


CThO1 Fig. 2. Controlled dispersion curves showing (a) negative dispersion, and (b) positive dispersion, both with fixed bandwidth. In each case, the peak is divided into two parts. For example, in the top set of curves (negative dispersion), only the 2-nm wide left part of the reflection spectrum is used for dispersion compensation, since the narrow portion of the grating peak corresponds to the unstrained uniform portion of the grating and has no time delay effects.



CThO1 Fig. 3. BER curves from a system demonstration with our compensator after 90-km transmission.

fixed bandwidth and fixed passband center wavelength. The available dispersion range is selectable by choosing a different bandwidth. Our concept has a simple structure, stable characteristics, and the same device can compensate both positive and negative dispersion. Furthermore, it can be used for dynamic compensation of groups of WDM channels simultaneously in single fixed passband.

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CThO2 **2:45 pm**

Tunable nonlinearly-bend-chirped fiber Bragg grating for third-order dispersion compensation

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1. Introduction

It has been shown that chirped fiber Bragg gratings (FBGs) can be used for the compensation of not only the group velocity dispersion (GVD) but also the 3rd-order dispersion (TOD).[1,2] However, conventional chirped FBG usually suffer from group-delay ripple (GDR) problem, typically > 10 ps, caused by stitching errors, step-chirp errors and fabrication imperfections. Due to the relatively low group delay value of the TOD component compared to that of the GVD, a low GDR is highly desirable for high-quality compensation. It will also be highly attractive if a device could offer a tunability in the TOD component, which is not possible in conventional devices.

In this paper, we propose a novel nonlinearly-bend-chirped FBG, which is tunable and has a low GDR, suitable for the compensation of TOD. We have demonstrated transmission of 10 GHz, 2.6 ps pulses over 98 km of dispersion-shifted fiber (DSF) with full TOD compensation using this device.

2. Device Design and Fabrication

A uniform FBG was fabricated using a standard uniform phase-mask and a scanning UV beam from a frequency-doubled Ar-ion laser at 244 nm. The FBG was 2.25 cm in length written in 2 minutes at a UV power of 40 mW. A tanh(5x) apodisation function was employed, resulting in a spectral width of 0.28 nm with low spectral side-lobes. Since the grating was formed in the fiber clamped together with the phase-mask, there was little phase error being introduced.

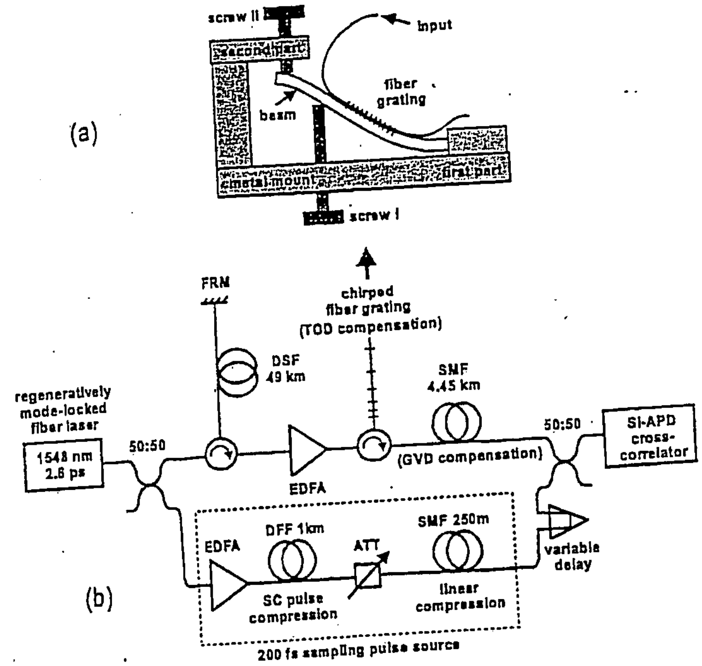
The FBG was bonded onto the surface of a beam substrate which was in turn mounted on a specially designed metal mount as shown in Fig. 1a. The first part of the mount is similar to the one featured in.[3] By adjusting the displacement of screw I (Fig. 1a) and hence the deflection of the first part of the beam, a tunable linear group delay can then be achieved. We have discovered that, when a second deflecting screw is added at the second part of the beam as depicted in Fig. 1a, a tunable TOD component can be introduced. By adjusting the two deflection-screws in an appropriate manner, one can tailor the spectral characteristics of the device, so that a different amount TOD can be realized.

3. Experiment and Results

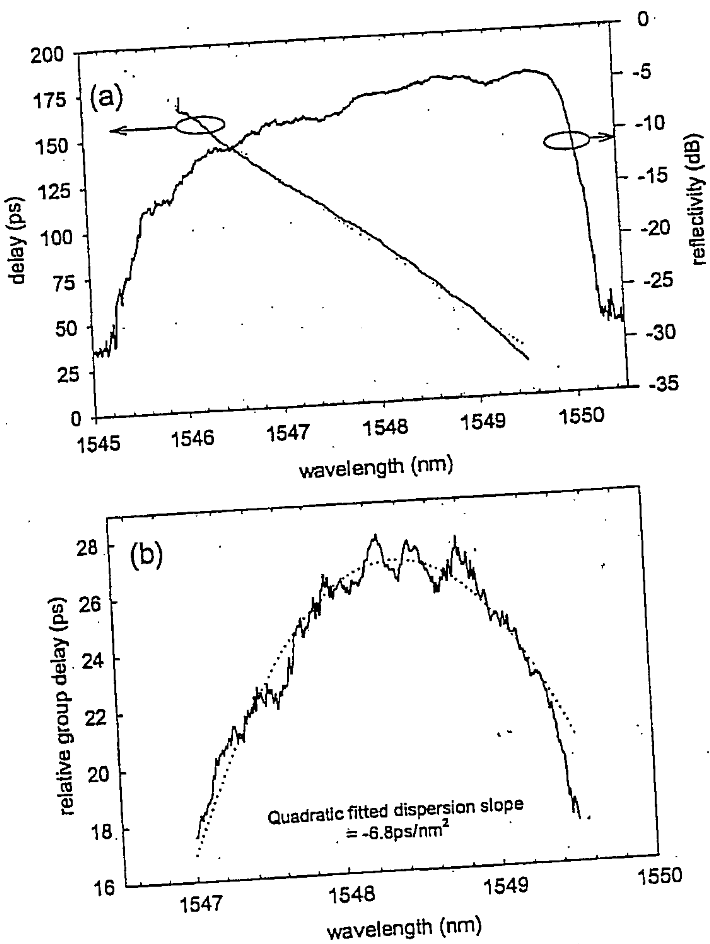
The spectral characteristics of the device are shown in Fig. 2a. It was adjusted to give a 3dB bandwidth of >2.5nm and a 10 dB bandwidth of >4 nm, centered at 1548 nm. It showed a linear group delay corresponding to 46 ps/nm (2.8 km SMF@16.7 ps/nm/km) and a quadratic group delay of −6.8 ps/nm^2 (97 km DSF@0.07 ps/nm^2/km). Fig. 2b shows the time delay of the device when its linear group delay (or GVD) is cancelled by 2.8 km of SMF. The deviation of the group delay from a quadratic fitting, over a bandwidth of 2.5 nm, is around ± 1ps, which is a record low value. Therefore, it is highly suitable for TOD compensation. Note that the small amount of GVD is required so that the TOD component can be realized. This GVD can be removed by either a linearly chirped FBG[2] or simply a length of SMF, as in our case.

In order to confirm the operation of this device, we have carried out an experiment as depicted in Fig. 1b. The output of a 10 GHz, 2.6 ps pulse source was transmitted through 98 km (2 × 49 km) of DSF with a Faraday rotator mirror. The TOD of the DSF was then compensated by the chirped FBG, which was tuned to match the incoming signal. The compensated signal was then examined through a highly-sensitive Si-APD cross-correlator[4] with 200fs sampling pulses.

The cross-correlation traces are shown in Fig. 3 for (a) the source pulse, (b) the compensated



CThO2 Fig. 1. (a) Design schematics of the nonlinearly-bend-chirped grating, and (b) experimental setup.



CThO2 Fig. 2. (a) Spectral reflection and delay characteristics of the chirped FBG. (b) TOD component of the group delay (solid line) with a quadratic fitting (dotted line).

pulse, (c) pulse distorted by the TOD of 98 km of DSF, and (d) pulse distorted by the TOD of the chirped FBG. The typical oscillatory tail of a TOD-distorted pulse is clearly visible in Fig. 3c and it was completely removed by the chirped FBG, yielding a fully compensated pulse (Fig. 3b). These results clearly show the effectiveness and viability of this device for TOD compensation in high bit-rate transmission systems.

4. Conclusion

We have designed and demonstrated a chirped FBG for TOD compensation using a novel bending mechanism. This device is tunable and posses a low GDR, which is highly suitable for TOD compensation in high bit-rate, short pulse transmission systems.

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CThO3 (Invited) **3:00 pm**

Terabit capacity transmission using Raman amplifiers

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WDM transmission experiments with multi-terabit capacity have been demonstrated by making use of the improved system margin from distributed Raman amplifiers. The role of hybrid Raman/Earbium amplifiers in high capacity WDM transmission systems will be discussed.

CThO4 **3:30 pm**

Remotely-pumped optical distribution networks

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We introduce a systematic approach to the design of WDM-aware IP networks[1] with emphasis on